PB90-125808

Role of Dietary Choices in the Ability of Bobwhite to Discriminate between Insecticide-Treated and Untreated Food

(U.S.) Corvallis Environmental Research Lab., OR

1989

U.S. Department of Commerce
National Technical Information Service
NTIS

ERL-COR-452J

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA/600/J-89/152	2.
3. R PB90-125808	
4. TITLE AND SUBTITLE Role of dietary choices in the ability of bobwhite to discriminate between insecticide-treated and untreated food	5. REPORT DATE
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Richard S. Bennett	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS US EPA ERL-Corvallis	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS US Environmental Protection Agency Environmental Research Laboratory 200 SW 35th Street Corvallis, OR 97333	13. TYPE OF REPORT AND PERIOD COVERED Journal Article
	14. SPONSORING AGENCY CODE EPA/600/2

15. SUPPLEMENTARY NOTES

1989 Environmental Toxicology and Chemistry 8:731-738.

16. ABSTRACT

Tests were conducted to determine the dietary concentrations at which 14-d old bobwhite chicks could discriminate between food treated with two organophosphorus insecticides and untreated food. Results of subacute dietary LC50 tests using one feeder of treated food per cage were compared with those of tests in which birds were presented with two feeders, one treated, one not, or 10 feeders (5:5 or 9:1). The dietary concentration above which birds discriminated between treated and untreated feeders by consuming a greater proportion of untreated was defined as the discrimination threshold(DT). The DT occurred at sublethal dietary concentrations in all chlorpyrifos tests, but increased in the methyl parathion tests as the number of choices and the relative proportion of treated feeders increased. The different responses were probably due to differences in the intensity of sensory cues presented by the two chemicals as the chicks developed conditioned aversions to them. In all tests, mortality was inversely related to total food consumption. No relationship was found between mortality and the amount of active ingredient ingested per bird-day. Consequently, the ability to locate untreated feeders was more important that the amount of chemical ingested.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 10
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

EPA/600/J-89/152

Environmental Toxicology and Chemistry, Vol. 8, pp. 731–738, 1989
Printed in the USA. Maxwell Pergamon Macmillan plc

0730-7268/89 $3.00 + .00

ROLE OF DIETARY CHOICES IN THE ABILITY OF BOBWHITE TO DISCRIMINATE BETWEEN INSECTICIDE-TREATED AND UNTREATED FOOD

RICHARD S. BENNETT
Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis, Oregon 97333

Abstract—Tests were conducted to determine the dietary concentrations at which 14-d-old bobwhite (*Colinus virginianus*) chicks could discriminate between food treated (TRT) with two organophosphorus (OP) insecticides (chlorpyrifos and methyl parathion) and untreated (UNT) food. Results of subacute dietary LC50 tests using one feeder of TRT food per cage were compared with those of tests in which birds were presented with two feeders (one TRT and one UNT, 1:1) or 10 feeders (five TRT and five UNT, 5:5; or nine TRT and one UNT, 9:1). The dietary concentration above which birds discriminated between TRT and UNT feeders by consuming a greater proportion of UNT food was defined as the discrimination threshold (DT). The DT occurred at sublethal dietary concentrations in all chlorpyrifos tests (DT = 45 ppm in 1:1 test, 24 ppm in 5:5 test and 69 ppm in 9:1 test; LC50 = 647 ppm) but increased in the methyl parathion tests as the number of choices and the relative proportion of TRT feeders increased (DT = 10 ppm in 1:1 test, 46 ppm in 5:5 test and >126 ppm in 9:1 test; LC50 = 91 ppm). The different responses were probably due to differences in the intensity of sensory cues presented by the two chemicals as the chicks developed conditioned aversions to them. In all tests, mortality was inversely related to total food consumption. No relationship was found between mortality and the amount of active ingredient ingested per bird-day. Consequently, the ability to locate UNT feeders was more important than the amount of chemical ingested. When alternative food choices exist, vulnerability to poisoning can be influenced by the number and relative abundance of those choices, as well as a bird's ability to detect the chemical.

Keywords—Dietary discrimination LC50 test Chlorpyrifos Methyl parathion Northern bobwhite

INTRODUCTION

The ability to detect and avoid toxic foods when nontoxic alternatives are available has been demonstrated in several avian species [1–5]. In controlled-feeding tests, birds reduced their dietary chemical exposure after developing conditioned aversions to treated food. A conditioned aversion may develop if an animal experiences illness after consuming chemically treated food and thereafter associates the illness with that food or other sensory cues [5]. The crucial factor in nature would be whether a bird stops consuming toxic foods before it ingests a lethal dose.

Several incidences of large avian die-offs have been linked to birds feeding in fields treated with organophosphorus (OP) or carbamate insecticides [6–9]. In most cases, acutely lethal doses may have been consumed rapidly before an aversion developed. However, little is known about the frequency of incidences in the field of animals responding to an initial chemical exposure by modifying foraging behaviors, such as switching to less toxic foods or different locations. Several field studies indicated that methiocarb, a carbamate, effectively repels birds from treated foods by instigating a conditioned aversion [10–12]. Many of the more commonly used OP and carbamate insecticides are less repellent and more toxic than methiocarb [13,14], but may still result in conditioned aversions that reduce birds' vulnerability to poisoning. Additional information concerning the factors and conditions that affect the ability of birds to detect and avoid toxic exposures is necessary to evaluate the potential of this behavioral response in lessening the hazard of a pesticide in the field.

This study was designed to evaluate one factor that could atler this behavior: how the numbers and relative proportions of treated and untreated food choices affect the ability of northern bobwhite (*Colinus virginianus*) chicks to discriminate be-

Mention of a company name or proprietary product does not constitute endorsement by the U.S. Environmental Protection Agency.

NTIS is authorized to reproduce and sell this report. Permission for further reproduction must be obtained from the copyright owner.

tween treated and untreated food. A series of feeding tests involving different combinations of feeders containing treated or untreated food was conducted to measure food aversion in response to two OP insecticides, chlorpyrifos (*O,O*-diethyl *O*-(3,5,6-trichloro-2-pyridyl)-phosphorothioate) and methyl parathion (*O,O*-dimethyl *O*-*p*-nitrophenyl phosphorothioate).

EXPERIMENTAL METHODS

Bobwhite chicks were used in one of four dietary tests consisting of combinations of chemically treated (TRT) and untreated (UNT) food: (a) 1 feeder per cage containing TRT food (dietary LC50 test); (b) 2 feeders per cage, 1 containing TRT and 1 UNT food (1:1); (c) 10 feeders per cage, 5 TRT and 5 UNT (5:5); and (d) 10 feeders per cage, 9 TRT and 1 UNT (9:1). At 10 d of age, birds were weighed and assigned to test cages using a stratified random procedure based on body weight [15]. At least 10 birds were tested in each cage. In the LC50 test, up to 30 birds per cage were used to also investigate the relationship between body weight and mortality. At 14 d, birds were weighed and presented with the test diets for 5 d. In each of the tests, the cages were assigned randomly to one of six dietary concentrations or a carrier control group. In the 5:5 and 9:1 tests, all of the TRT feeders within a cage contained the same dietary concentration.

Both chlorpyrifos (purity 94%) and methyl parathion (purity 95.8%) were dissolved in corn oil in a 65°C waterbath. The corn oil solution was mixed 2:98 (w/w) with Purina gamebird starter diet for 10 min. The control diet contained corn oil in the same proportion.

Birds were housed in brooder cages measuring 70 × 91 × 22 cm, and maintained at 35°C on a 14-h light:10-h dark cycle. The LC50 and 1:1 tests used rectangular galvanized steel chick feeders, whereas the 5:5 and 9:1 tests used 500-ml rectangular polyethylene bottles with four 2.5-cm holes in the sides for feeding. Bottles were arranged in two rows of five, aligned from front to back in each brooder and held in place by metal frames. Because birds can quickly develop preferences among feeder positions, feeders were moved daily to reduce the association of toxic effects with a particular location and to force birds to respond to the stimuli of the food itself. The positions of feeders in the 1:1 test were changed daily on a random schedule. To ameliorate the effects of potential feeder position bias in the 5:5 and 9:1 tests, each feeder was placed in each of the five positions in the tray for equal periods during the 5-d treatment, using a stratified random schedule. Food and water were provided ad libitum, with each feeder containing more than the total daily consumption.

Food consumption, clinical signs of toxicity and mortality were recorded daily in the LC50 test during the 5-d treatment and 3-d posttreatment periods. Food consumption was calculated as grams consumed per bird-day, where bird-day equaled the average of the numbers of birds alive at the beginning and end of each 24-h period. Individual body weights were recorded on days 0, 5 and 8. The same measurements were taken in the food choice tests, except that all surviving birds were asphyxiated at the end of the 5-d treatment period to determine brain cholinesterase (ChE) activity. Brains of birds that died during tests were also assayed for ChE activity immediately or within 1 to 4 d (held refrigerated at 2–5°C).

Brain ChE activity was determined by a modification of the Ellman procedure [16]. Whole brains were homogenized in pH 7.4 Tris buffer at ratios of 35 mg/ml with a Virtis 45 homogenizer at 30% speed for 15 s. The entire homogenate was centrifuged for 20 min at 18,800 *g* under refrigeration (2–5°C), and the supernatant was refrigerated (0–5°C) until assayed (within 5 h). The supernatant was analyzed for ChE activity using a calibrated Perkin-Elmer Lambda 1 UV/VIS spectrophotometer (wavelength 412 nm) connected to an automatic recorder for measurement of the reaction rate. Acetylthiocholine iodide (ACTI) was used as the substrate, and activity was expressed as μmol ACTI hydrolyzed/min/g brain tissue. Since treatment groups were not replicated, the ChE activity of a group was considered inhibited if it was more than 20% below the control activity [17].

In the LC50 tests, the median lethal concentration (LC50) and 95% confidence interval were calculated by probit analysis using the Statistical Analysis System (SAS) computer software package [18]. In the food choice tests, the primary endpoint was not mortality but the ability of birds to respond to the presence of chemically contaminated food. The dietary concentration above which birds discriminated between treated and untreated foods by consuming a higher proportion of untreated food was defined as the discrimination threshold (DT). It was calculated as the intersection of a two-phase regression using the log of the ratio of UNT to TRT food consumption over the 5-d test period as the dependent variable and the log of the concentration of TRT food as the independent variable [19]. In the 9:1 tests, birds feeding at random would consume 90% TRT food. In these tests the

dependent variable is modified to $y = \log [(UNT/TRT)/(1/9)]$, to account for the change in relative availability of the two food types so that the expected value for y equals 0 at concentrations below the DT.

RESULTS

Mortality of bobwhite in the LC50 tests increased as dietary concentrations of chlorpyrifos and methyl parathion increased (Table 1). The onset of intoxication in the bobwhite was characterized by reduced food consumption and diarrhea within 48 h, followed by lethargy, wing droop, muscular incoordination, tremors and tetany immediately preceding death. The LC50 values (95% confidence interval) were calculated to be 647 ppm (564, 737) for chlorpyrifos and 91 ppm (82, 101) for methyl parathion. Mean body weights of controls increased more than 50% during the treatment period, while remaining unchanged or decreasing in all dietary concentrations that caused mortality (Table 1). Dead birds lost 20 to 47% of their body weight during treatment, with an average loss of 38 ± 1% (SE) for both OP insecticides. Total food consumption decreased sharply as dietary concentration increased in LC50 tests (Figs. 1 and 2). As a result, total amount of active ingredient ingested during the treatment period was similar for all dietary concentrations (Table 1).

In the 1:1 tests, total food consumption was similar between controls and treatment groups because increases in UNT food consumption compensated for reductions in TRT food consumption at concentrations above the DT (Figs. 1 and 2). No mortality, intoxication or weight loss was observed (Table 1). DTs (95% confidence interval) occurred at 63 ppm (20, 163) and 10 ppm (3, 18) for chlorpyrifos and methyl parathion, respectively, and were 7 and 11% of the LC50 values. Both values were below the dietary concentrations that resulted in mortality in the LC50 tests.

DTs in the 5:5 and 9:1 tests with chlorpyrifos occurred at 26 ppm (23, 44) and 71 ppm (22, 197), respectively, and were also below the concentrations that resulted in mortality. Although birds were able to detect the presence of chlorpyrifos at relatively low concentrations, some mortality did occur in the highest dietary concentrations in the 9:1 test (Fig. 1). The increased amount of sampling required to discriminate between TRT and UNT food may have resulted in higher levels of chemical ingestion than in the LC50 test (Table 1). Also, total food consumption was reduced by as much as 48% in the 9:1 test.

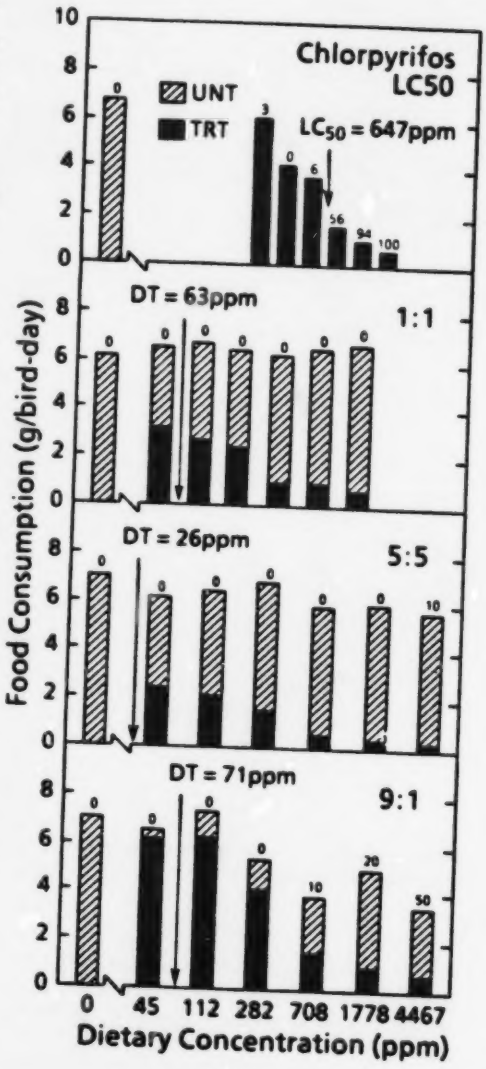

Fig. 1. Mean daily food consumption of bobwhite presented various combinations of chlorpyrifos-treated and untreated food choices. Values above each bar represent percent mortality during 5-d treatment period. The discrimination threshold (DT) represents the dietary concentration above which bobwhite discriminated between treated and untreated feeders.

With methyl parathion, the DT increased as the number of feeders and the proportion of TRT feeders increased (Fig. 2). The DT in the 1:1 test was 10 ppm, as compared with 45 ppm (29, 64) in

Table 1. Percent mortality, dietary exposure, weight changes and brain combinations of insecticide treated and untreated

Test	Dietary conc. (ppm)	N	% mortality, days 0–5	Chemical ingested (mg/kg/d)	% body weight change (days 0–5) $\bar{x}$	SE	Range	Brain ChE (% control) $\bar{x}$	Range
Chlorpyrifos									
LC50	0	18	0	0	55	1.3	46, 67		
	178	18	0	33.5	50	1.7	36, 61		
	282	18	0	37.0	25	5.2	−22, 52		
	447	18	6	49.7	6	5.1	−33, 46		
	708	18	56	38.0	−32	3.5	−44, 8		
	1,122	18	94	46.0	−40	0.9	−45, −32		
	1,778	18	100	51.7	−36	1.8	−46, −20		
1:1	0	10	0	0	35	1.2	30, 41	100	94, 104
	40	10	0	3.6	32	1.2	24, 36	102	95, 113
	80	10	0	6.2	40	1.6	[illegible] 47	99	95, 107
	160	10	0	10.4	41	1.3	36, 49	99	90, 107
	320	10	0	11.3	36	1.6	27, 43	94	86, 105
	640	10	0	10.9	36	1.0	32, 42	104	89, 116
	1,280	10	0	13.7	38	1.1	32, 41	101	92, 106
5:5	0	20	0	0	36	0.7	31, 42	100	90, 110
	45	10	0	3.2	34	1.9	23, 44	102	94, 112
	112	10	0	6.6	26	2.8	16, 44	99	87, 125
	282	10	0	12.7	33	5.8	−10, 61	96	83, 106
	708	10	0	14.9	25	3.0	9, 40	98	74, 112
	1,778	10	0	25.7	25	3.1	9, 38	96	87, 112
	4,467	10	10	38.2	19	5.5	−28, 38	94	59, 112
9:1	0	20	0	0	51	1.1	42, 60	100	92, 109
	45	10	0	8.6	53	1.4	46, 61	103	95, 115
	112	10	0	21.5	54	1.7	46, 62	98	81, 110
	282	10	0	36.7	33	3.7	12, 48	75	57, 92
	708	10	10	37.4	15	7.1	−28, 38	66	46, 88
	1,778	10	20	53.3	17	11.0	−44, 50	86	61, 102
	4,467	10	50	108.7	−7	12.2	−43, 52	71	45, 104

See the text for description of tests.

the 5:5 test and more than 126 ppm in the 9:1 test. Total food consumption was reduced at concentrations above the DT in the 5:5 test (Fig. 2). Mortality occurred only in the 200 ppm group, in which food consumption was 23% of that of controls, with no discrimination between TRT and UNT feeders. Birds in this group sampled extensively between feeders but did not show a preference for UNT food on any day of the treatment period. The resulting high ingestion of active ingredient may have caused the reduced consumption of all food.

In the methyl parathion 9:1 test, discrimination between feeders was not observed until 200 ppm, when only 53% of total consumption was of TRT food. Consequently, the mortality pattern in this test was similar to that in the LC50 test. The responses of individual birds at the 200 ppm level were highly variable. Five birds that died lost an average of 38% of initial body weight, whereas survivors gained as much as 17%. Individual variation was also observed in the chlorpyrifos 9:1 test, where weight changes for individuals during treatment ranged from −44 to 52% in the highest concentrations (Table 1).

Average brain ChE activity was similar to that of controls in both 1:1 tests and the chlorpyrifos 5:5 test, regardless of the amount of chemical ingested (Table 1). ChE activity was inhibited (>20% depression) [17] only in treatment groups in which total food consumption was reduced (Table 1). Consequently, when the mean values for each treatment group were pooled for the three multiple-feeder tests, there was a significant correlation between ChE activity and total food consumption for chlorpyrifos ($r = 0.78$, $n = 21$, $p < 0.01$) and methyl parathion ($r = 0.89$, $n = 21$, $p < 0.01$). ChE

cholinesterase (ChE) activity in bobwhite chicks presented various food in separate feeders during a 5-d treatment

Test	Dietary conc. (ppm)	N	% mortality, days 0–5	Chemical ingested (mg/kg/d)	% body weight change (days 0–5)			Brain ChE (% control)	
					$\bar{x}$	SE	Range	$\bar{x}$	Range
Methyl parathion									
LC50	0	30	0	0	53	0.9	43, 62		
	50	30	3	4.0	−2	3.3	−35, 25		
	63	30	10	3.5	−18	2.7	−46, 9		
	79	30	23	3.5	−22	2.8	−46, 6		
	100	30	53	3.7	−31	2.4	−44, 7		
	126	30	57	3.7	−34	1.6	−44, −4		
	159	30	83	3.2	−40	1.3	−47, −13		
1:1	0	10	0	0	36	1.3	32, 44	100	91, 114
	13	10	0	1.2	45	1.2	40, 52	102	89, 114
	20	10	0	1.4	41	2.0	34, 55	96	90, 111
	32	10	0	1.9	42	1.6	31, 49	97	76, 111
	50	10	0	1.7	36	0.9	31, 39	99	83, 114
	79	10	0	2.6	36	2.2	21, 48	93	76, 106
	126	10	0	3.8	35	1.4	29, 45	95	74, 124
5:5	0	10	0	0	60	2.3	47, 69	100	91, 112
	20	10	0	2.3	54	1.8	46, 63	95	87, 110
	32	10	0	3.4	50	2.4	41, 64	91	70, 104
	50	10	0	3.5	18	4.9	−4, 37	73	48, 99
	79	10	0	4.8	34	4.4	9, 52	83	59, 104
	126	10	0	4.4	18	6.2	−16, 48	81	40, 102
	200	10	80	5.6	−27	4.0	−36, 6	52	37, 77
9:1	0	20	0	0	51	1.1	42, 60	100	92, 109
	20	10	0	2.9	34	2.2	21, 43	75	54, 94
	32	10	0	3.6	8	6.1	−28, 36	61	34, 79
	50	10	0	4.8	−4	4.6	−29, 19	51	32, 65
	79	10	60	4.0	−29	5.1	−38, 13	61	45, 95
	126	10	80	5.5	−35	2.2	−40, −17	53	21, 76
	200	10	50	6.4	−24	6.7	−42, 17	64	46, 84

activity in birds that died during the treatment period was depressed an average of 43 and 42% in the chlorpyrifos and methyl parathion tests, respectively.

Total food consumption also was related to mortality. No mortality was observed in any treatment group in which total consumption was greater than 5.8 or 3.1 g/bird-d for chlorpyrifos and methyl parathion, respectively (Fig. 3). For treatment groups with lower average consumption, mortality was inversely related to consumption in all tests using chlorpyrifos and methyl parathion. Because consumption of TRT food decreased with increasing dietary concentrations greater than the DT, there was generally little or no increase in the amount of active ingredient ingested. Consequently, no relationship was observed between mortality and amount of chemical ingested.

DISCUSSION

The ability to detect and avoid lethal dietary exposures to OP insecticides can be influenced by the number and relative proportion of TRT and UNT food choices. The DT, the dietary concentration above which birds discriminated between treated and untreated foods by consuming a higher proportion of UNT food, was approximately an order of magnitude less than the LC50 values in both 1:1 tests, indicating that chlorpyrifos and methyl parathion were similarly detected in this situation. However, the DT remained at sublethal concentrations in all chlorpyrifos tests, while increasing significantly in methyl parathion tests as the number of feeders or relative proportion of TRT feeders increased. This indicates that a stronger sensory cue was associated with food treated with chlorpyrifos

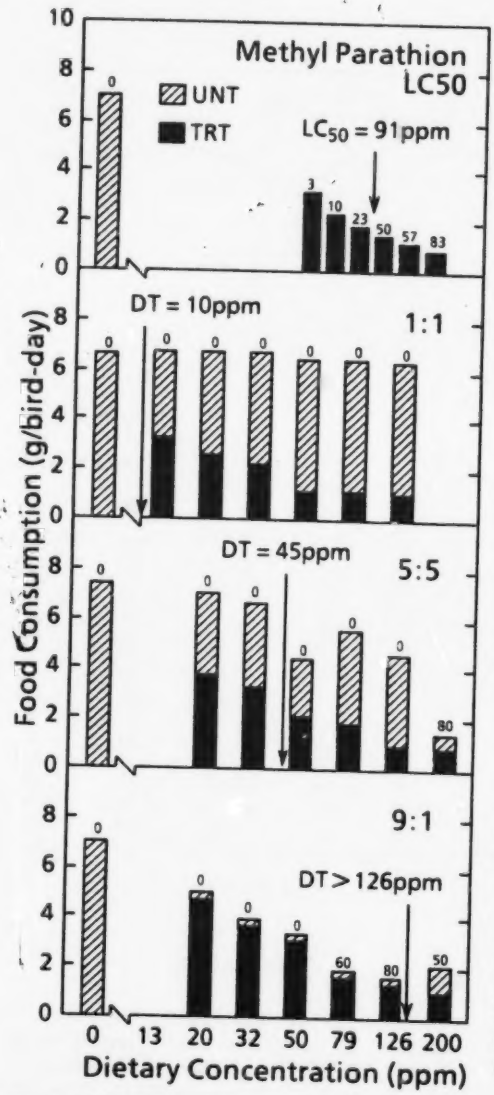

Fig. 2. Mean daily food consumption of bobwhite presented various combinations of methyl parathion-treated and untreated food choices. Values above each bar represent percent mortality during 5-d treatment period. The discrimination threshold (DT) represents the dietary concentration above which bobwhite discriminated between treated and untreated feeders.

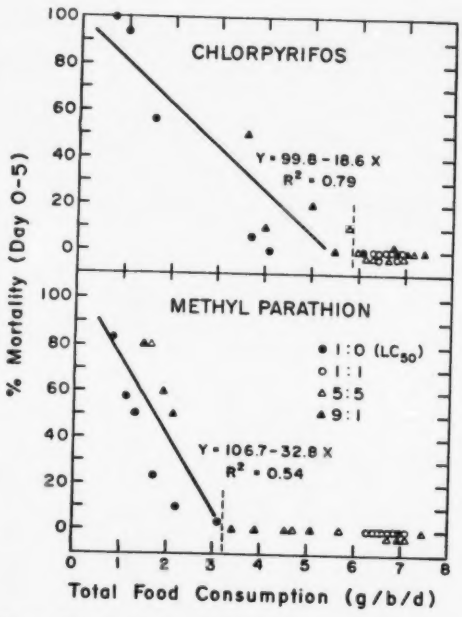

Fig. 3. Relationship between total food consumption and percent mortality, with data from all treatment groups combined.

than with that treated with methyl parathion, which affected the development of conditioned aversions.

Conditioned aversions may develop if an animal associates a food, water or place with an illness or other negative reinforcer, resulting in avoidance of that item in subsequent encounters [5]. If contaminated food is associated with a detectable sensory cue, animals may form aversions to that cue, but not necessarily to the food type if uncontaminated food is available. If chemical cues are weak or undetectable, consumption of both contaminated and uncontaminated food of that type may be reduced. However, aversive conditioning can be effective in reducing hazard only if suitable food alternatives exist and are readily available to the animal.

In this study, birds in many treatment groups appeared to identify the available sensory cues and responded by discriminating between TRT and UNT food. In most treatment groups, discrimination was not apparent during the initial exposure to TRT food, as might be expected with repellent chemicals. Rather, the birds began to discriminate between TRT and UNT food on subsequent feedings, suggesting that conditioned aversions developed after 12 to 24 h of exposure. Birds in other treatment groups discriminated poorly between foods throughout the 5-d test, resulting in greater consumption of active ingredient than in treatment

groups that did discriminate. These birds may not have been able to associate the illness they experienced with either TRT or UNT food, and consumption of all food decreased.

In the LC50 tests, mortality was related to the dietary concentration, but birds consumed similar amounts of active ingredient (mg/kg) in each dietary concentration. Grue [20] reported a similar response in grackles (*Quiscalus quiscula*) and suggested that mortality was largely due to pesticide-induced anorexia. Grue found that birds exposed to OP insecticides, either in food or by oral gavage, significantly reduced consumption of all food, treated or untreated, for up to 12 h. Similarly, Pope and Ward [21] concluded that mortality in weaverbirds (*Quelea quelea*) following epidermal applications of fenthion was caused by anorexia. Adams [22,23] and Glow et al. [24] found that depression of brain ChE activity resulted in reduced appetitive behavior and food consumption in rats, leading to loss of body weight.

Reductions in consumption of both TRT and UNT food and significant weight loss in the birds that died in these tests may have resulted from pesticide-induced anorexia, as indicated by the inverse relationship between total food consumption and mortality. Inhibition of brain ChE activity was also observed in treatment groups that showed reduced food consumption and body weights. There were a few treatment groups in which ChE activity and total food consumption were not reduced, yet the amount of chemical consumed was similar to the toxic concentrations in the LC50 test, demonstrating that ChE depression is dependent on more than the amount of chemical ingested. The total amount of food consumed had a significant impact on the response produced by a particular amount of chemical ingested. For example, birds in the 126 ppm treatment groups of the methyl parathion 1:1 and 5:5 tests had exposures similar to those in the LC50 test (3.7–4.4 mg/kg/d), but total food consumption was 6.3, 4.7 and 1.1 g/bird-d, respectively. No mortality was observed in the 1:1 or 5:5 tests, compared with 57% mortality in the LC50 test. The survival of an individual bird was more dependent on its ability to locate UNT food than on the amount of insecticide ingested.

This study was designed to test only the ability of bobwhite to detect the presence of pesticides in one type of food; there were no additional visual cues. When TRT food is paired with alternatives that are visually distinct (e.g., using color treatments or different food types), birds are averted more readily from TRT food and switch to alternatives whether the cues are detectable or not [5]. Ring-necked pheasants (*Phasianus colchicus*) will switch to less preferred food types when their most preferred foods are contaminated with pesticides [4]. Since visual cues are more important to birds than taste or olfactory cues in the formation of conditioned aversions [25], aversion to even undetectable chemical treatments is possible, provided that the bird properly associates the illness with the treated food type and suitable alternatives are available.

Conditioned aversions to foods contaminated with highly toxic insecticides must develop rapidly to prevent acute poisoning. This does not always happen, however, since many field die-offs occur when relatively abundant and preferred foods are contaminated with highly toxic insecticides. Little is know about field conditions in which birds respond to the presence of toxic insecticides by changing their foraging patterns, thereby changing their chemical exposure. However, this study indicates that, in addition to inherent differences in the detectability of different chemicals, the number of food choices and the relative proportion of contaminated food can have an important effect on the foraging responses of bobwhite.

Acknowledgement—I thank H. V. Kibby and B. A. Williams for making this project possible, R. K. Ringer and J. K. Bennett for critically reviewing the manuscript, and C. Maguire, D. W. Schmedding, D. Bonfoey and T. Shiroyama for technical assistance and chemical analysis.

REFERENCES

1. **Hill, E.F.** 1972. Avoidance of lethal dietary concentrations of insecticide by house sparrows. *J. Wildl. Manage.* **36**:635–639.
2. **Kenaga, E.E., R.J. Fink** and **J.B. Beavers.** 1979. Dietary toxicity tests with mallards, simulating residue decline of chlorpyrifos and avoidance of treated food. In E.E. Kenaga, ed., *Avian and Mammalian Wildlife Toxicology*. STP 693. American Society for Testing and Materials, Philadelphia, PA, pp. 36–44.
3. **Schuler, W.** 1980. Factors influencing learning to avoid unpalatable prey in birds re-learning new alternative prey and similarity of appearance of alternative prey. *Z. Tierpsychol.* **54**:105–143.
4. **Bennett, R.S.** and **H.H. Prince.** 1981. Influences of agricultural pesticides on food preference and consumption by ring-necked pheasants. *J. Wildl. Manage.* **45**:74–82.
5. **Conover, M.R.** 1984. Response of birds to different types of food repellents. *J. Appl. Ecol.* **21**:437–443.
6. **Seabloom, R.W., G.L. Pearson, L.W. Oring** and **J.R. Reilly.** 1973. An incident of fenthion mosquito control and subsequent avian mortality. *J. Wildl. Manage.* **9**:18–20.

7. **Stone, W.B.** 1979. Poisoning of wild birds by organophosphates and carbamate pesticides. *N.Y. Fish Game J.* **26**:37–47.
8. **White, D.H., K.A. King, C.A. Mitchell, E.F. Hill** and **T.G. Lamont.** 1979. Parathion causes secondary poisoning in a laughing gull breeding colony. *Bull. Environ. Contam. Toxicol.* **23**:281–284.
9. **Flickinger, E.L., D.H. White, C.A. Mitchell** and **T.G. Lamont.** 1984. Monocrotophos and dicrotophos residues in birds as a result of misuse of organophosphates in Matagorda County, Texas. *J. Assoc. Off. Anal. Chem.* **67**:827–828.
10. **Ingram, C.R., R.T. Mitchell** and **R.A. Stickley.** 1973. Hopper box treatment of corn seed with methiocarb for protecting sprouts from birds. *Proc. Bird Contr. Sem.* **6**:206–215.
11. **Rogers, J.G.** and **J.T. Linehan.** 1977. Some aspects of grackle feeding behavior in newly planted corn. *J. Wildl. Manage.* **41**:444–447.
12. **Rooke, I.J.** 1984. Methiocarb-induced aversion to grapes by gray-backed white-eyes. *J. Wildl. Manage.* **48**:444–449.
13. **Schafer, E.W., Jr., W.A. Bowles, Jr.,** and **J. Hurlbut.** 1983. The acute oral toxicity, repellency, and hazard potential of 998 chemicals to one or more species of wild and domestic birds. *Arch. Environ. Contam. Toxicol.* **12**:355–382.
14. **Schafer, E.W., Jr.,** and **R.B. Brunton.** 1971. Chemicals as bird repellents—Two promising agents. *J. Wildl. Manage.* **35**:569–572.
15. **Steel, R.G.D.** and **J.H. Torrie.** 1960. *Principles and Procedures of Statistics.* McGraw-Hill, New York, NY.
16. **Ellman, G.L., K.D. Courtney, V. Andres, Jr.,** and **R.M. Featherstone.** 1961. A new and rapid colorimetric determination of acetylcholinesterase activity. *Biochem. Pharmacol.* **7**:88–95.
17. **Ludke, J.L., E.F. Hill** and **M.P. Dieter.** 1975. Cholinesterase (ChE) response and related mortality among birds fed ChE inhibitors. *Arch. Environ. Contam. Toxicol.* **3**:1–21.
18. **SAS Institute, Inc. 1982.** *SAS® User's Guide: Statistics.* Cary, NC.
19. **Bennett, R.S.** and **D.W. Schafer.** 1988. Procedure for evaluating the potential of birds to avoid chemically contaminated food. *Environ. Toxicol. Chem.* **7**: 359–362.
20. **Grue, C.E.** 1982. Response of common grackles to dietary concentrations of four organophosphate pesticides. *Arch. Environ. Contam. Toxicol.* **11**:617–626.
21. **Pope, G.G.** and **P. Ward.** 1972. The effects of small applications of an organophosphate poison, fenthion, on the weaver-bird, *Quelea quelea. Pestic. Sci.* **3**:197–205.
22. **Adams, P.M.** 1973. The effects of cholinolytic drugs and cholinesterase blockade on deprivation-based activity and appetitive behavior. *Neuropharmacology* **12**:825–833.
23. **Adams, P.M.** 1977. Effects of anticholinergic and cholinesterase blocking drugs on appetitive behavior under different deprivation conditions. *Life Sci.* **21**: 129–136.
24. **Glow, P.H., A. Richardson** and **S. Rose.** 1966. Effects of acute and chronic inhibition of cholinesterase upon body weight, food intake, and water intake in the rat. *J. Comp. Physiol. Psychol.* **61**:295–299.
25. **Wilcoxon, H.C., W.B. Dragoin** and **P.A. Kral.** 1971. Illness-induced aversions in rat and quail: Relative salience of visual and gustatory cues. *Science* **171**: 826–828.

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This article documents research that was conducted under the auspices of the U.S. Environmental Protection Agency (USEPA). As an arm of the government, the USEPA has a paid up, non-exclusive, irrevocable, worldwide license to reproduce, prepare derivative works, and distribute to the public all of the material contained herein, and to grant others acting on its behalf the right to do so. The USEPA grants to the National Technical Information Service, Department of Commerce, the right to act as its agent in the distribution of this material.